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IVTH INTERNATIONAL CONFERENCE ON ELECTROMAGNETIC WINDOWS

T. C. CHESTON

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The IVth International Conference on Electromagnetic Windows took place on 10-12 June 1981 near Toulon, France. Thirty-one papers were presented describing developments of radomes for aircraft, missiles, and ground-based stations for both microwave and IR application. The papers are briefly summarized and some of the comments made during the discussion periods are reported.

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IVTH INTERNATIONAL CONFERENCE ON ELECTROMAGNETIC WINDOWS

The IVth International Conference on Electromagnetic Windows took place on 10-12 June 1981. The conference, which was organized by the French Navy (Direction des Construction et Armes Navales de Toulons), was held in the Convention Center of Bendor, a small island near Toulon, France. The island was large enough to accommodate three hotels where the participants stayed. It was pre-vacation season and very few other people were there. This provided an excellent environment in which the participants could get to know each other, and shoptalk prevailed at leisure time. A total of some 110 people were registered. The absence of participants from eastern Europe was noted.

Thirty-one papers were presented at the conference, and two additional papers were available in print. This report contains brief descriptions of all the papers delivered, in the order of listing, together with specific comments which may have been made in answer to questions. The authors' names and affiliations are given so that further information can be obtained by writing directly to them. Rough translations of the titles are included where applicable. The presentations were in either French or English with not-quite-adequate instantaneous translations being available.

SESSION I. RADOME ANALYSIS AND DESIGN

(1) Amélioration de la Méthode de Calcul du Lobe de Réflexion de Radome d'Avion. (Improved Method of Calculating Reflection Lobes from Aircraft Radomes). (E. Gimonet, A. Sarremejean, ONERA CERT, 2, Av. Edouard Belin, 31055 Toulouse, France.)

In this presentation, Gimonet described calculations of the radiated nearfield of an antenna and methods of interfacing it with a radome. "Flashpoint" sidelobes due to reflections from within the radome were derived using a plane-wave spectrum approach. Good agreement was found with an experimental radome, 17 λ in diameter and 16 λ long.

(2) Théorie Asymptotique de la Propagation Appliquée au Calcul de l'Aberration d'un Radome. (An asymptotic Method of Calculating Radome Aberrations). (G. Debionne, Societe Thomson CSF, 178, Blvd. Gabriel Peri, 92240 Malakoff, France.)

The author discussed a method of calculating radome aberrations which is halfway between a simple ray-tracing technique and an accurate evaluation of the nearfield of the antenna. The nearfield is calculated using an asymptotic method based on and extending previous work by Choudary and Felsen (*Proc. IEEE*, Nov. 74). Experimental verification was said to show generally good agreement with the value and position of the maximal errors.

(3) Comparative Accuracies of Radome Analysis Methods. (G.K. Huddleston, H.L. Bassett, Georgia Institute of Technology, Atlanta, GA 30332, USA.)

Three computer-aided methods of calculating radome aberrations were compared in this presentation. The first method used ray-tracing, and the antenna was considered the receiver; the second employed a plane-wave-spectrum representation with the antenna transmitting; and the third made use of surface integration. The calculations were compared with experimental results obained with small, medium, or large four-horn monopulse antennas. Substantially poor agreement was found between the three prediction methods and with measured data; this was especially the case with the small antenna. Comments from the floor suggested that perhaps the poor antenna design produced misleading results since, it was said, even simple methods of calculation gave better agreement with good antennas. The speaker suggested that perhaps inhomegeneities in the radome caused the disparities of the results. The lack of agreement between many of the theoretical results remained unexplained.

(4) Inductive Wire Matching Techniques for Dual Frequency Microwave Antennas and Radomes. (A.M. Munro, G.N. Taylor, J.G. Gallagher, Royal Signals and Radar Establishement, Malvern, England.)

Dielectric radome materials can be loaded with conducting wires parallel to the E-vector to give them free-space characteristics with a dielectric constant of unity, at least for some conditions of incidence angle. The use of wire grids for matching was discussed in this paper and applied to aircraft radomes with high angles of incidence and operating at two frequencies. Broken wire grids were also investigated which could be made transparent at one frequency and made to reflect at another frequency. Experimental results showed that radome aberrations were reduced with wire matching. About 20% bandwidth was claimed. It should be remembered that this technique is polarization sensitive and lacks the type of circular symmetry that is needed for missile radomes. Comments from the floor were made, suggesting the inclusion of diodes with the wires, as used with the "Radant" phased array, but with the diodes adjusted to improve the band width.

(5) Transmission et Réflexion d'une Onde Electromagnétique Plane Incidente sur un Radome Renforcé par des Fils. (Transmission and Reflection of EM Plane Waves Incident on a Wire-Reinforced Radome). (R. Crampagne, H. Echapasse ONERA CERT, 2, Av. Edouard Belin, 31055 Toulouse, France.)

In this paper a generalized theoretical treatment of the same subject as that discussed in the previous paper was given. Transmission through a dielectric sheet reinforced with wire gratings was calculated, together with the reflection coefficient and the transmission insertion phase. An arbitrary wire orientation relative to polarization was taken. Good agreement was shown with experimental results.

(6) Une Méthode Simple et Souple Permettant l'Analyse de la Transmission á Travers une Plaque Métallique Percée de Trous. (A Simple and Flexible Method of Calculating Transmission through a Metal Plate Perforated with Holes.) (R. Crampagne, ONERA CERT, 2, Av. Edouard Belin, 31055 Toulouse, France.)

Perforated metal sheets can be made transparent under certain conditions of angles-of-incidence, polarization, etc., and might therefore find application for radomes. The authors derived transmissibility equations, which they claimed were simpler than previous methods for plates filled with a regular pattern of holes.

(7) The Calculation of Diffraction Effects of Radome Lightning-Protection Strips. (S.W. Waterman, British Aerospace, Six Hills Way, Stevenage, Herts, England.

It is, perhaps, not obvious that aircraft traveling from cloud to cloud can be hit by lightning, but radomes have been known to be struck with most serious effects. The nosedome of an aircraft, therefore, needs lightning protection. In this paper, a method of calculating the near-field diffraction effects of metal strips commonly used for lightning protectors was presented. The currents on the strips were represented as line sources. Boresight losses and aberrations as well as sidelobe degradation and crosspolarization effects were then predicted. Good experimental verification was shown.

(8) La Prévision du Comportement Radioélectrique d'un Radome lors d'un Vol à Grande Vitesse (programme ASR). (The Prediction of the EM Behavior of a Radome during High-Velocity Flight.) (D.L. Balageas, D. Engrand, J. Bordas, A. Sarremejean, E. Gimonet, ONERA CERT, 2, Av. Edouard Belin, 31055 Toulouse, France.)

The authors described the computer simulation program ASR (Aérothermique-Structure-Radioélectricité) for calculating in-flight radome effects. It is composed of 3 separate, independent parts, simulating respectively thermal, structural, and EM parameters. Experimental verification included measurement of a silicon-glass radome at Mach 6 in a wind tunnel and its EM measurements when subjected to thermal shock in a solar furnace.

(9) Radome Rain Damage--An Environmental Analysis Technique. (B.J. Crowe, Flight Systems, Inc., Newport Beach, CA 92660.)

This paper was presented for the author by a colleague. It contained rainfall statistics, gave cumulative path rainfall (in/hr × nm) probabilities, and related these, in one example, to an empirical Pyroceram 9609 stress failure factor that had been proposed by Weckesser.

(10) High Power Twist Polarizer-Radome for a Phased-Array Antenna. R. Lo Forti, Elettronica S.P.A., via Tiburtina, Rome, Italy.)

The paper was presented by a colleague of the author. It briefly described an EW-jamming system comprising a high-power phase-scanned line-array protected by a cylindrical twist polarizer-radome combination that rotated horizontal polarization to 45°. The phased array consisted of 16 microwave horns that were narrow and adjacent in the E-plane. Scanning was with phaseshifters to ±45°. The paper concentrated on the polarizer-radome which was designed with 3 successively rotated layers of thick metal strips on DuPont's KAPTON sheets. Performance figures quoted were remarkably good: power density—15 W/cm^2; insertion loss <0.5 dB; bandwidth—2 octaves; polarization error <1 dB.

SESSION II. MATERIALS AND TECHNOLOGY

(11) The Use of Modern Materials and Techniques in Radome Design. (B.V.A. Wickenden, F.S. Ward, Plessey Co. Ltd., Wood Burcote Way, Towcester, Northampton, England.)

The authors reviewed various radome design options, for example, thin, half-wave solid, sandwich, and metal insert types, and followed this by a discussion of available plastic or glass materials in solid form or foamed (but excluding ceramics), and of rain erosion protection. A qualitative comparison matrix of the various properties was given. Temperatures up to 200°C were considered. In answer to questions, polyester resins (RPB) were quoted as being temperature limited at 175°C, and polyurethane at 120°C. The rain erosion coating KEMGLAZE was given as having $\varepsilon = 3.4$ and $\tan \delta = 0.03$.

(12) Propriétés Diélectriques d'un Stratifié Verre-Résine PSP. (Dielectric Property of Stratified Glass-Resin Poly[styrylpyridine]). (J. Touraine, Electronique Marcel Dassault, 55 Quai Carnot, 92214 St. Cloud, France).

The presentation started with the observation that the resin PSP, poly(styrylpyridine), had been developed for ONERA (Office National d'Etudes et de Récherches Aérospatiales) for materials that can be reinforced with carbon or boron fibers for high-temperature applications. The actual material used and tested was PSP resin reinforced with 15 layers of fiberglass (E-glass 200664/1383-300 gr/cm^2). Flat samples were assembled and tested and repeatable results were obtained. The dielectric constant averaged about 4.40 at 20°C rising to 4.57 at 400°C. The loss tangent varied a little more from sample to sample, averaged 0.015, and never exceeded 0.0187 up to 400°C. This temperature was claimed to be safe for prolonged exposure and could be exceeded for short periods. A 4-foot-high radome was built by injection molding (see also paper #23).

(13) A New Material for Radome Construction. (M.C. Cray, M.G. Taylor, British Aerospace, Six Hills Way, Stevenage, Herts, England.)

Syntactic foams consist of microspheres embedded in an organic resin matrix. The authors described various development types of syntactic foams that were being developed for application in an A-type sandwich radome. A series of samples with fabric/resin skins and with erosion coatings were tested both electrically and for rain erosion resistance on a 223 m/s whirling arm with 25 mm/hr rain. It was concluded that syntactic foam was electrically suitable with a wide range of different resins and that under severe rain-impact conditions it outperformed similar constructions based on honeycomb and rigid polyurethane-foam cores.

(14) A Materials Study to Find an Advanced Optical Window Material for 8-12 μm Applications. (J.A. Savage, K.J. Marsh, Royal Signals and Radar Establishment, Malvern, England.)

In the 8-12 μm range, the existing radome materials, germanium and ZnS, were stated to be inadequate when elevated temperatures and rain-erosion conditions are encountered. A little-known family of refractory rare earth compounds that should have advanced IR properties was discussed by the authors. First results were obtained with $SrLa_2S_4$ and are described in this paper. In these early efforts, small yellow crystals were produced which showed a hardness twice that of the ZnS. In answer to a question, workers at Pennsylvania State University were said to have obtained 20-30% transmissibility with thin $S_rLa_2S_4$ materials in the 8-12 μm region.

(15) Traitement de Surface des Fenetres Infra-Rouges. (Surface Treatment of IR Domes). (P. Froissart, Y. Touze, Societe Anonyme de Télécommunications, 41, rue Cantagrel, 75013 Paris, France.)

The authors discussed IR windows for the 8-12 μm band for application at relatively low temperatures (-4 to +50°C) when germanium becomes a suitable material. Surface treatment, it was claimed, achieved impedance matching and thereby increased the efficiency. The surface treatment consisted of depositing multiple thin films with properly selected values of dielectric constant. The finish was found acceptable for conditions of rain at velocities up to 150m/sec and the hope was expressed that the next generation would have acceptable rain-erosion-resistance characteristics at even higher velocities.

(16) Fenetres Infra-Rouges en Fluorure de Magnésium. (Magnesium Fluoride IR-Domes). (J. Meneret, CRD CEC, 2, av. Albert Einstein, BP No. 59, 78193 Trappes, France.)

Production of magnesium fluoride windows for the 4-5 μm band was discussed in this paper. The material started as a powder, went successively through hot and cold presses, and finally was polished. An 8-cm-diameter hemispherical sample was shown. Flat pieces up to 20 cm in diameter could be made. In reply to questions, the production yield was quoted as 80%; the material was said to be stable for at least a number of years; and magnesium fluoride was considered easier to process than magnesium chloride.

(17) Multilayer Broadband Radome Using Thermoplastic Materials. (E. Greene, IBM Corp., Owego, NY 13827, USA.)

The title of this paper was not very apt, since the presentation did not include a discussion of bandwidth (it was learned later that bandwidth information was classified). It did include a description of a thermoplastic, rain-impact-resistant, C-sandwich radome development. The material chosen was a thermoformed polycarbonate. Samples were tested both mechanically and for rain impact with a rotating-arm test apparatus. The material was said to be significantly superior to conventional quartz-cloth/thermosetting epoxy designs in its resistance to rain erosion, with pitting of the surface occurring only after 20 minutes at speeds of 600 mph (268 m/sec) and no pitting taking place at 500 mph (222 m/sec).

(18) Les Composites Silice-Silice: Matériaux de Fenetres d'Antennes Soumis à des Ambiances Thermiques Sévères. (The Composite Silica-Silica: Materials for Radomes that are Exposed to Severe Thermal Conditions). (J. Jamet, ONERA, 29 av. de la Division Leclerc, 92320 Chatillon sous Bagneux, J.Y. Bourcereau, R. Raymond, Aerospatiale, 37 Blvd. Montmorency, 75781 Paris Cedex 16, France.)

A mind-boggling description of a 3-D silica-fiber weaving process was given. The application was for space reentry vehicles in which as much as 10 MW/m^2 is generated for several seconds. After weaving with threads going in the x,y,z directions, the material is repeatedly dipped into a liquid containing colloidal silica and is dried, after each immersion, until a density of at least 1.65 is obtained. The material was tested and showed an excellent thermal shock resistance (10 MW/m^2 for several seconds); it gave good thermal isolation (temperature near antenna <100°C) and had a dielectric constant that was substantially invariant (2.9) up to to 1000°C.

(19) Tetra-Fluoro-Ethylene Coated Fabric Composites as Radome Membranes. (M.B. Punnett, Birdair Structures, Div. of CHEMFAB, 2015 Walden Avenue, Buffalo, NY 14225, USA.)

The speaker described a relatively new proprietry material: fiberglass or Kevlar coated with Teflon. Punnett said that this material was thin, light, and pliable as well as water repellent, and that it had considerable strength. It had been used for radomes in various ground applications.

(20) Radome for Use on Submarines. (B.V.A. Wickenden, W.G. Howell, Plessey Co. Ltd., Wood Burcote Way, Towcester, Northamptons., England.)

This paper was presented by F.S. Ward, also from Plessey, and contained a description of the harsh environmental conditions that a submarine-mounted radome would encounter. High transmissibility over, typically, an octave band was required. An experimental radome made from polyester syntactic foam was described and test results were given.

(21) Fabrication du Radome de l'Avion "Mirage 2000." (Fabrication of the "Mirage 2000" Radome). (R. Carbone, Atelier Aviation, D.C.A.N., Toulon 83390 Cuers Marine, France.)

The author described the radome development for the new combat aircraft Mirage 2000, which flies at Mach 2.2. The radome must withstand temperatures of 135°C. It is constructed with preimpregnated fiberglass stockings, contains 31% resin, and has 2% voids. The material was said to have a dielectric constant of 3.5±0.1 and a loss tangent of .017. In reply to a question, the speaker said that the rain erosion-coating was applied by hand and was only 0.2 mm thick, but he claimed that this was adequate and had been checked experimentally.

(22) Fabrication and Test of Organic Resin Radomes for High Temperature Applications. (A. Campbell, M.C. Cray, British Aerospace Dynamics Group, Stevenage, Herts., England.

Various resin materials for glass-reinforced radomes were discussed in this paper. The speaker described a specific injection-molded radome, which contained a resin that was an addition-cured polyimide based on a eutectic mixture of bismaleimides. The radome was reinforced with woven glass-fiber shapes. Preliminary stress tests were reported with temperatures that rose to 350°C on the outer wall (300°C on the inner wall) in 3½ minutes, and that were maintained under load for 3 minutes. Minor small-area delaminations occurred in the vicinity of the heaters and these were attributed to constrained thermal expansion. For long-term exposure, a maximum temperature of 220°C was suggested.

(23) Fabrication par Injection de Radomes Stratifiés Haute Température à Matrice Organique PSP. (Fabrication of High-Temperature Injection-Molded Radomes using the Organic Matrix PSP). (B. Bloch, ONERA, 29 av. de la Division Leclerc, 92320 Chatillon sous Bagneux, France.)

This paper was similar in scope to the previous one in which injection-molded radomes were discussed. The chosen resin was PSP poly(styrylpyridine) designated 6022 PC, reinforced with glass stockings made from "E" glass, style 181. The material consisted of about 46% of fibers by volume and had 1.5-3% voids. Samples were tested to 350°C for periods of at least 15 minutes and substantially retained their mechanical strength over that range. Radomes were 40 cm high, 20 cm in diameter and 5 mm thick (see also paper #12).

SESSION III. ENVIRONMENTAL CONSIDERATIONS--RADOME TESTING

(24) Tenue à la Foudre d'un Radome d'Avion. (Response of an Aircraft Radome to Lightning). (M. Diet, EMD Electronique Marcel Dassault, 55 Quai Carnot, 92214 St. Cloud, France.)

Actual tests of lightning protectors were described in this paper. A 5×10^6-volt, 60-kJ-energy voltage source and a 50-kV, 100-kJ-energy current source were used. Satisfactory protection was obtained with metal strips.

(25) Mach 5 Rain Erosion Resistance of Hot-Pressed Silicon Nitride at High Angles of Impact. (F.P. Meyer, J.F. Dignam, US Army Materials & Mechanics Research Center, Watertown, MA 02172, USA.)

The authors discussed rain-erosion tests conducted with the rocket sledge at Holloman AFB, NM. Samples were exposed to 67 mm/hr of rain over a 610-m range with an average raindrop size of 1.4 mm. Velocities of Mach 5 and 6 were used. The samples were constructed for various angles of incidence. Results were presented for hot-pressed silicon nitride (HPSN), SiALON (cold-pressed and sintered silicon aluminum oxynitride) and fused silica. The important parameter during such a test is $V\sin\theta$ where V is the velocity and θ is the angle of incidence. The value $V\sin\theta$ is therefore the velocity component normal to the surface. A thick sample (1.27 cm) of HPSN survived with $V\sin\theta = 902$ m/sec without any damage. A thin-walled (0.64 cm) sample suffered no rain erosion under the same conditions, but cracked and failed catastrophically. SiALON survived $V\sin\theta = 690$ m/sec without damage. Slip-cast fused silica experienced surface damage at $V\sin\theta = 497$ m/sec. During question time the following points were brought out: surface finish is considered very important and surfaces should be highly polished; HPSN contains needles and rounded particles, and the microstructure is self-reinforced; HPSN is difficult to manufacture and it would be very difficult and expensive to use it for a complete radome, while SiALON, pyroceram, and alumina are much easier materials to work with.

(26) Evaluation et Mesures en Soufflerie des Déformations d'un Radome Dues aux Forces et aux Echauffements Aérodynamiques. (Test and Evaluation of Radome Deformations with Windloads and Aerodynamic Heating). (E. Engrand, J. Bordas, M. Portat, A. Bruere, J. Cassaing, D. Balageas, ONERA, 29 av. de la Division Leclerc, 92320 Chatillon sous Bagneux, France.)

This paper tied in with paper #8, which described a computer-simulation program for in-flight radome behavior. Theoretical and experimental results were compared with a fused silica radome subjected to aerodynamic forces and heating corresponding to Mach 6 flights. Good agreement was claimed for both temperature gradiants and deflections.

(27) Behavior of Fiber Reinforced Fluorocarbon Radome Materials in Aerothermal and Rain-Erosion Sled Tests. (K.N. Letson, US Army Missile Command, USA.)

This paper was presented by F. Meyer (see paper #25) and gave further results from the Holloman AFB sled tests, this time for fiber-reinforced fluorocarbon radomes. The sled and rain conditions were as given in paper #25. Many different fibers and methods of construction were tested. Fibers were short or continuous and ranged from polymers to glasses. Tabulations of results were presented.

(28) Mach 2 Rotating Arm Rain Erosion Test Apparatus. (K.W. Foulke, Naval Air Development Center, Warminster, PA 18974, USA.)

Rain erosion testing was also the subject of this paper (see two preceding papers) which described the rotating arm installation at NADC. In this device, samples were propelled through an artificial rain field with normal incidence ($\sin\theta = 1$) at velocities reaching up to Mach 2.0. A raindrop size of 2 mm, adjusted to give 12.7 mm/hr of rain, was adopted as standard.

(29) The Application of Compact Test Ranges for Radome Measurements. (C. McCartney, British Aerospace, Six Hills Ways, Stevenage, Herts., England.)

McCartney described a compact radome-test range where the desired far-field response is obtained by testing in the nearfield of a large aperture over which phase and amplitude are constant. This large aperture is an offset-fed paraboloid with an efficient corrugated-horn-type feed. The test range is in an anechoic chamber where low reflection side-walls are of particular importance. The facility has been evaluated at C-, X-, and Q- band, and excellent agreement was shown to exist with measurements at larger, more conventional, far-field ranges.

(30) Computerized Logarithmic Antenna Pattern Receiver. (H. Larsson, B. Thylen, Bofors Plas, Box 149, S-34100, Ljungby, Sweden.)

In this paper from Sweden, the authors described a receiver for an antenna-pattern measuring system where the performance over a band of frequencies is recorded. A swept-frequency transmission is used and the antenna pattern is recorded showing maximal and minimal values in dB's and also the average. Unfortunately, the average which is recorded is not average power but average dB's.

(31) Caractérisation de Matériaux dans les Gammes d'Ondes Millimétriques. (Characterization of Materials at Millimeter Wavelengths). (P. Boderies, B. Chan-Song-Lint, ONERA/CERT, 2 Av. Edouard Belin, B.P. 4025, 31055 Toulouse, France.)

This paper was presented by a colleague from the same organization, who described a method for measurement of dielectric constant and loss tangent at millimetric wavelengths. An open cavity was used in two configurations. In the first, two spherical mirrors faced each other and shared the same center point (focus). The second configuration consisted of a spherical mirror on one side and a plain mirror at the center facing it. In both cases the sample is placed at or near the focus and changes in resonant frequency and in Q are measured, from which the dielectric constant and the loss tangent can be derived. A typical set-up had a base line of 30 cm and was used at 90 GHz. Accuracies of about 1.5% in $(\varepsilon-1)$ and 10% in $\tan\theta$ were claimed.

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